Simulated Design of Quantum Networks

Senior design team sddec23-17

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Problem Statement & Design Context

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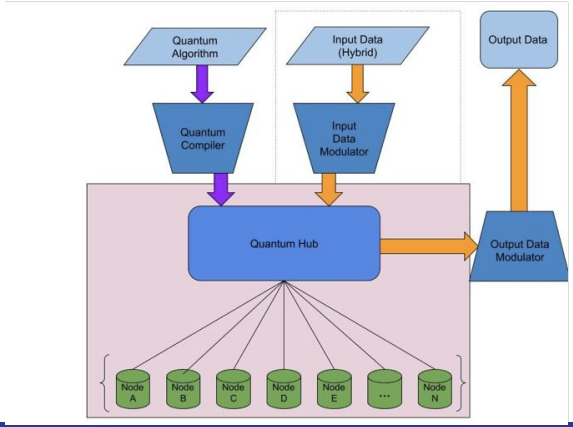
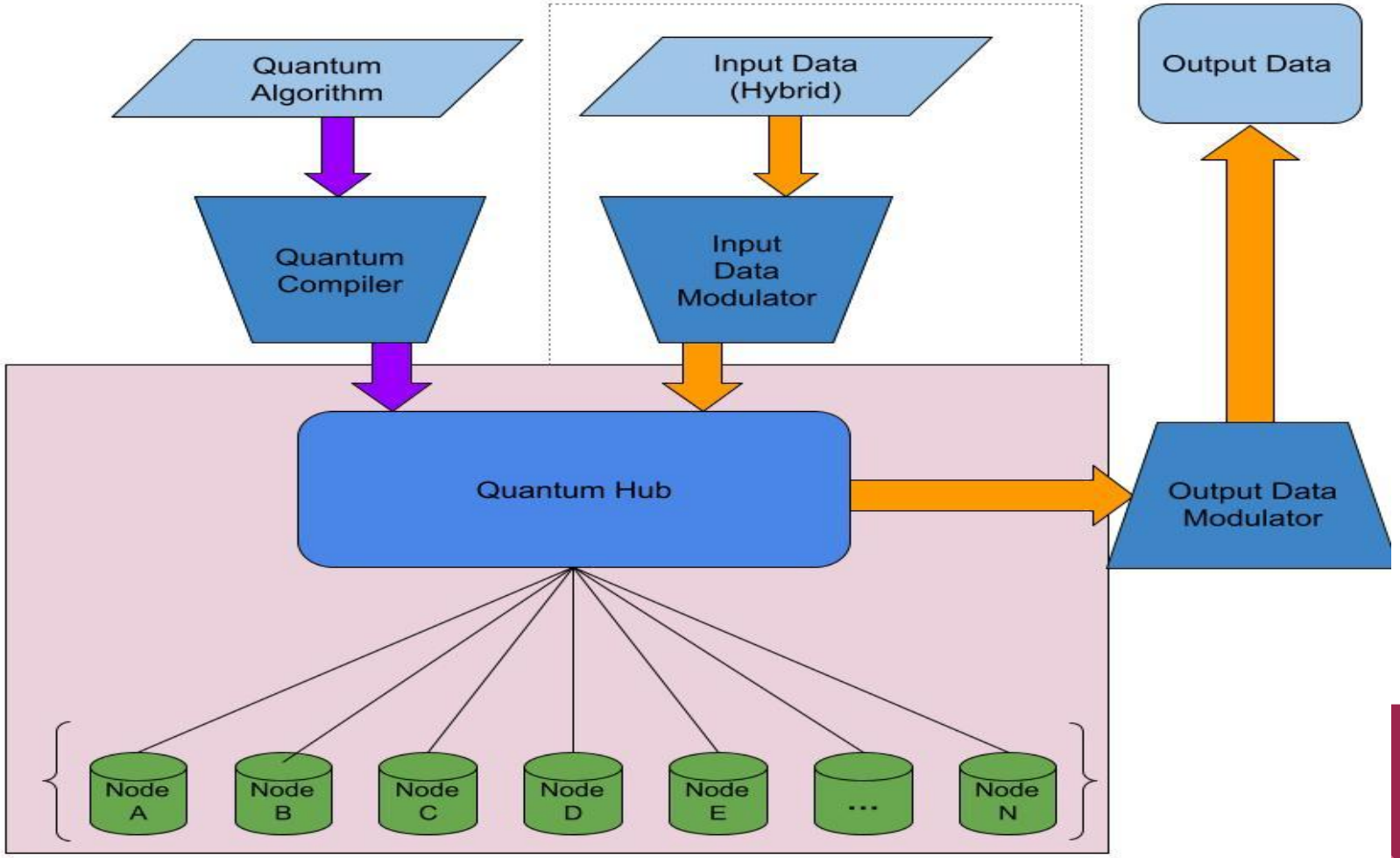
- Client: Dr. Durga
  - Doing intensive research regarding quantum computers.
  - Major interest : **Quantum computation** and **Quantum information theory**
    - **Working making Ion traps to hold Q-bits. Also research in future of quantum computing clusters.**
- Needs:
  - Design a quantum network **simulation** to communicate with quantum cluster computers. These computers will have both classical and quantum components.

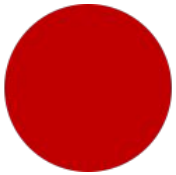



Quantum Algorithm
Input Data (Hybrid)
Output Data
Quantum Compiler
Input Data Modulator
Quantum Hub
Output Data Modulator
Node A
Node B
Node C
Node D
Node E
...
Node N

What is Quantum Computing

Classical Computers (Digital Computers)

Bits



Or

0

1

Quantum Computers

Qbits

$$a|0> \ +b|1>$$

0

1

Why does the superposition matter?

How many numbers are need to describe 2 bits versus 2 Qbits

Classical Computers

2 bits -> 00, 01, 10, and 11 *(only 2 numbers enough)*

Quantum Computers

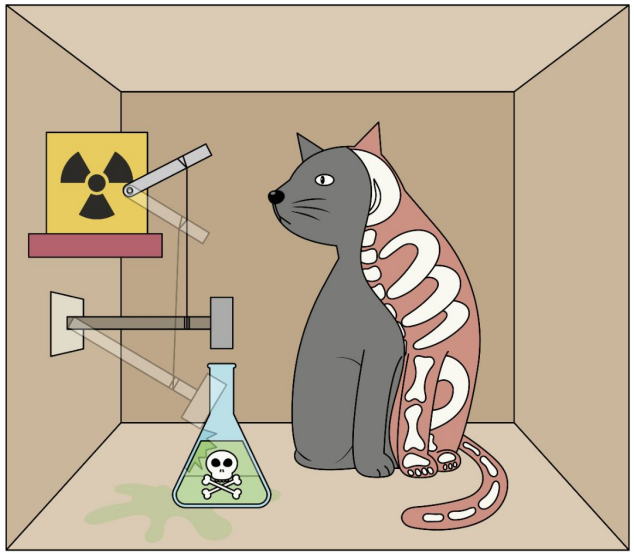
$$a|00>, \quad b(|01>+|10>), \quad c(|01>-|10>), \quad d|11>$$

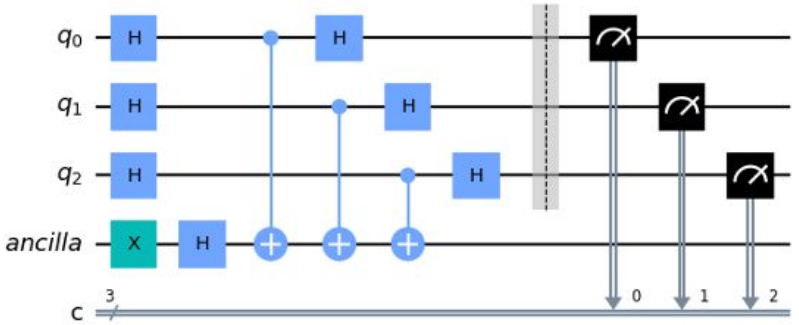
(we need 4 numbers)

N Qbits -> 2^N Bits

2^{300} = Number of particles in Universe

More concepts (Measurements, Entanglement)





Engineering Standards and Protocols

IEEE 802.3 Ethernet: This standard defines the physical and data linky layers of wired Ethernet networks. These networks are going to be critical to set up as they will be used in conjunction with our quantum network we are creating and provide a good baseline network that we can build off of.

IETF RFC 2544: Methodology for measuring the performance of network devices. This standard from the Internet Engineering Task Force describes standards on how network devices are monitored and how their performance is tracked. Once our network is running, we will need to test the speed and reliability using these standards to ensure that it is a viable option compared to standard internet.

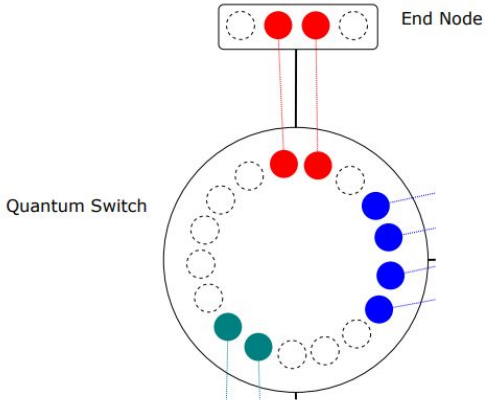
IEEE P7130: Standard for Quantum Computing Definitions. These standards provide standards on how quantum computing framework functions are described and what terminology is used. This is important because if we are to communicate with our advisor, we will need to use the proper terms so that he can understand and implement our design.

IEEE P802.1Q-2021: Bridges and Bridged Networks, Amendment 28: Quantum Key Distribution Protocol. This amendment to IEEE 802..1Q defines the Quantum Key Distribution (QKD) protocol which is used to secure network traffic over a quantum network. This is important because if we want the traffic on our network to be secure therefore we will need to implement QKD.

Project plan

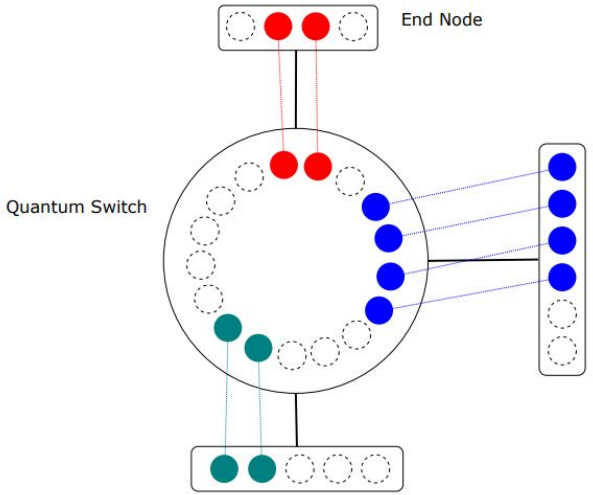
1st Iteration - Communication Between Router and Node

- Make sure that node and router have basic communication
- Node will return structured answer to the problem
- Router must take that information and produce an answer for user



2nd Iteration - Customization

- The user should choose how many nodes will execute the problem
- The user can pick if nodes to all the work or part of the work
- The router will not give the user any control of what the answer will look like



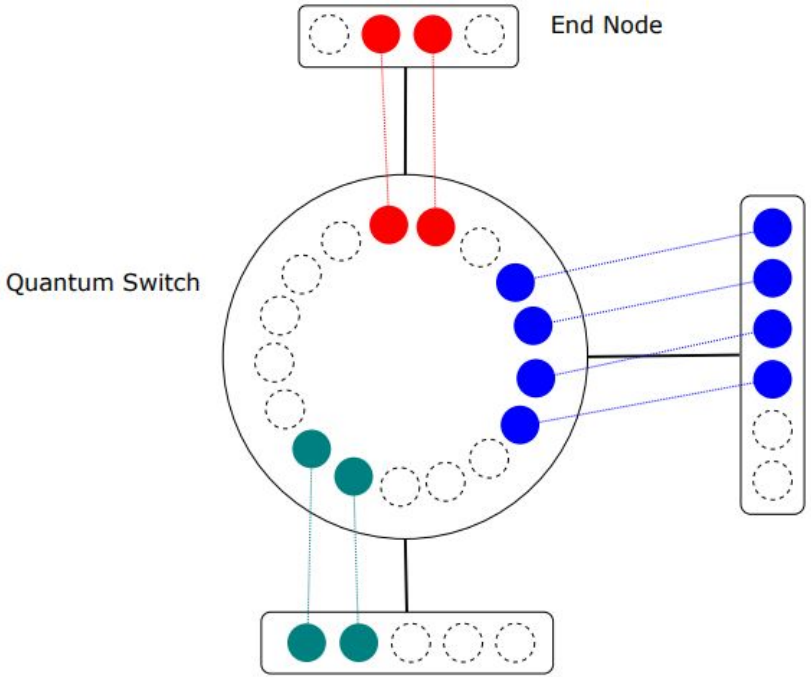
3rd Iteration - Statistical analysis

- The user can choose to program their own analysis of the program or use what is given

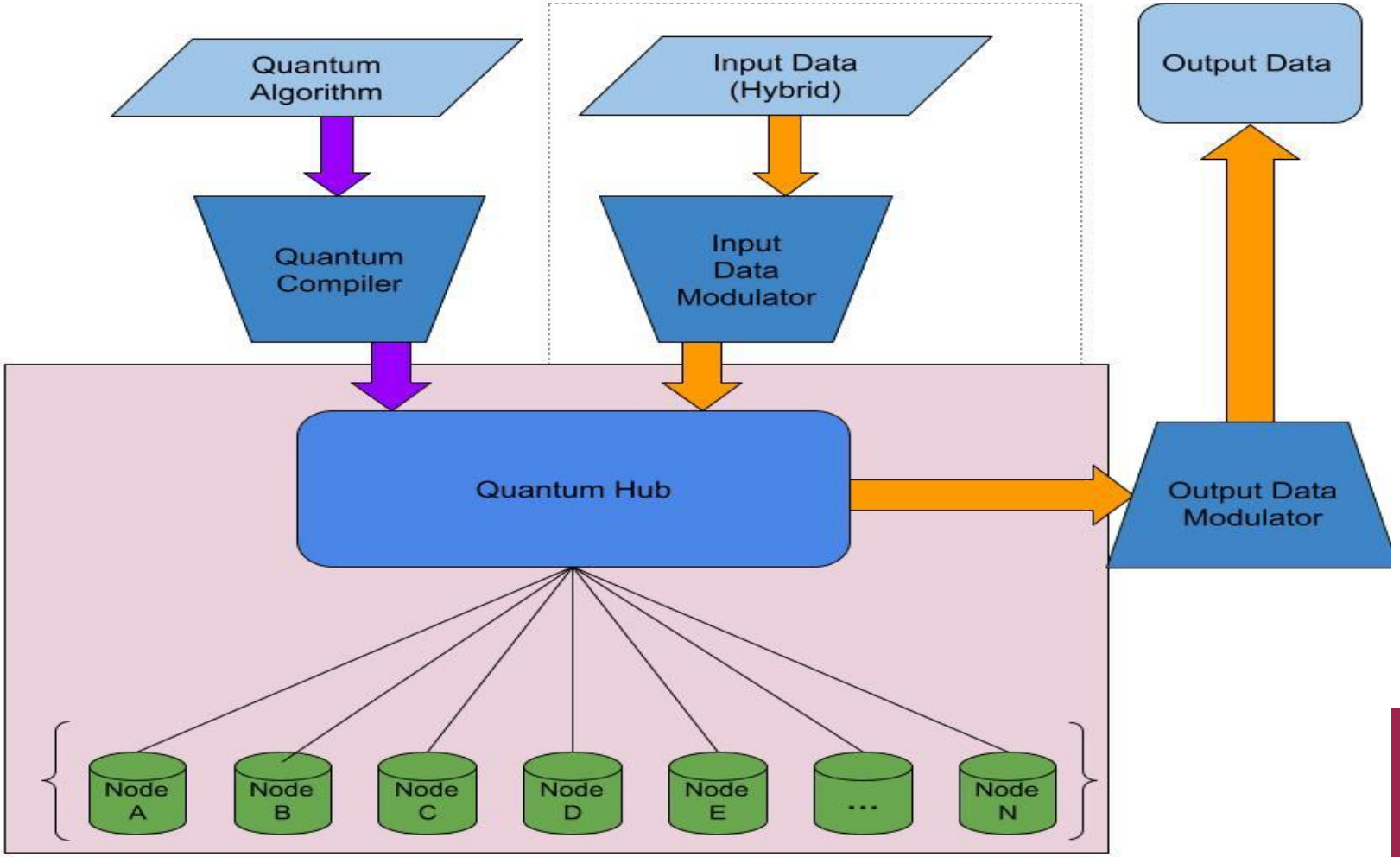
- The user can output the data to an xml file
  - Where each row is the node number and its answer to the problem

Evolving design

- Our understanding of our project has changed over the course of the semester as we have come to understand our clients needs and increased our understanding of quantum computing.



- Source: https://arxiv.org/pdf/2110.04116.pdf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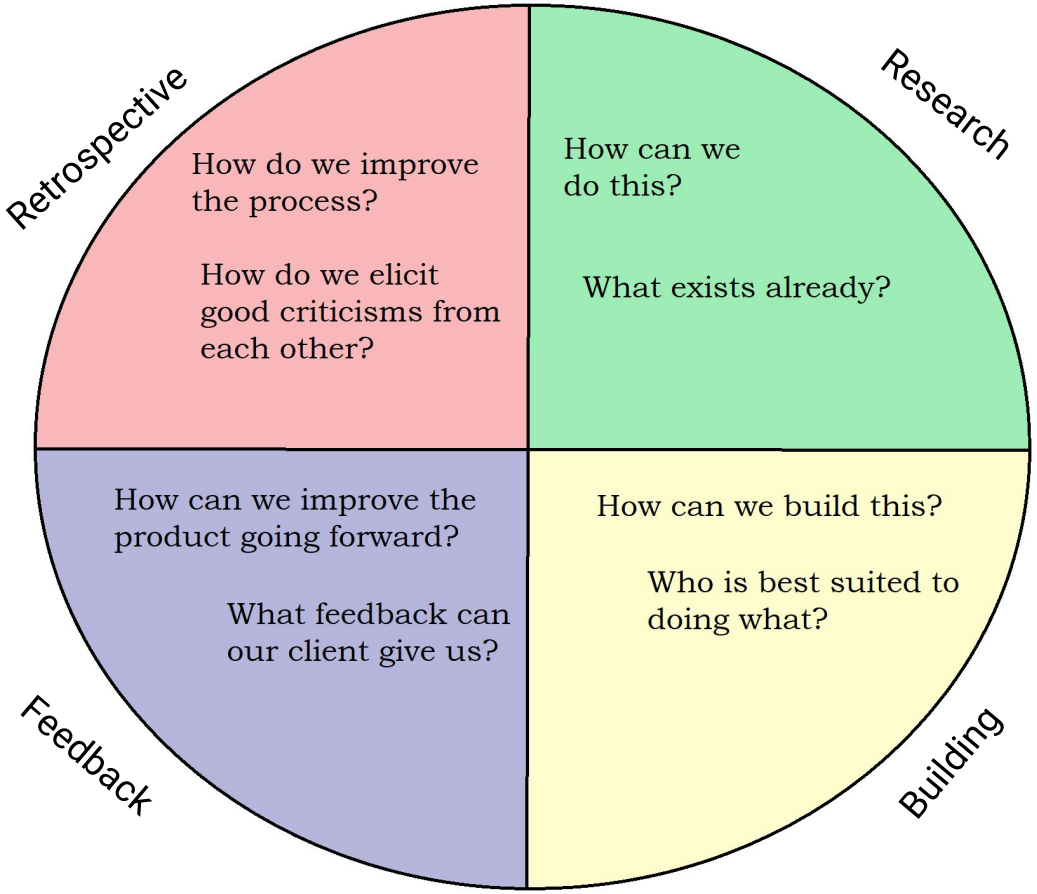
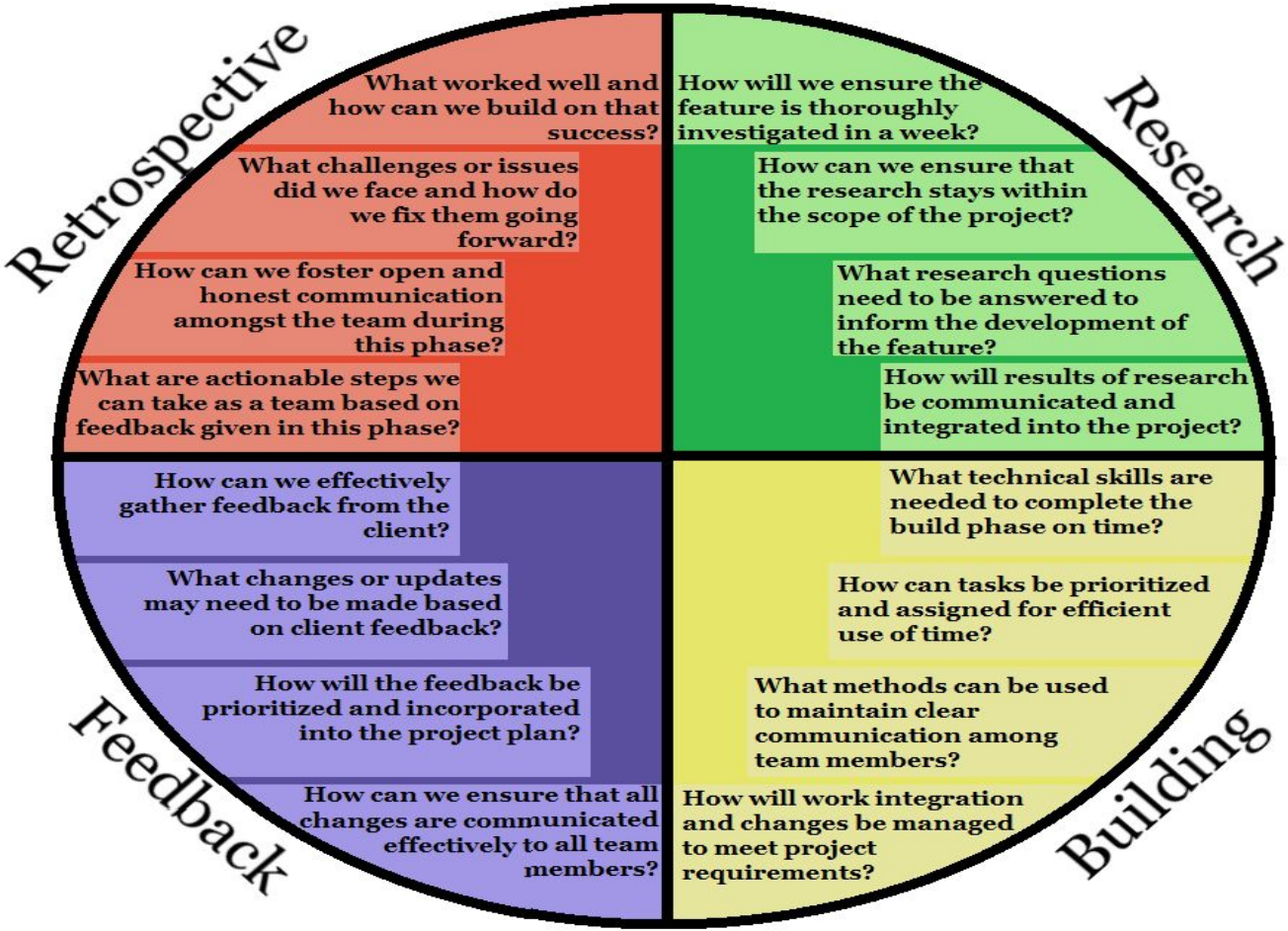
Why does this matter?

- This evolving design matters because it informs us about what approach is best for managing our project.
  - We decided on a primarily agile approach with some aspects of waterfall.
    - Agile type sprints with a uniform period of time (1 week) dedicated to each aspect of the sprint.


Retrospective
How do we improve the process?
How do we elicit good criticisms from each other?
Research
How can we do this?
What exists already?
Feedback
How can we improve the product going forward?
What feedback can our client give us?
Building
How can we build this?
Who is best suited to doing what?


Retrospective
What worked well and how can we build on that success?
What challenges or issues did we face and how do we fix them going forward?
How can we foster open and honest communication amongst the team during this phase?
What are actionable steps we can take as a team based on feedback given in this phase?
Research
How will we ensure the feature is thoroughly investigated in a week?
How can we ensure that the research stays within the scope of the project?
What research questions need to be answered to inform the development of the feature?
How will results of research be communicated and integrated into the project?
Feedback
How can we effectively gather feedback from the client?
What changes or updates may need to be made based on client feedback?
How will the feedback be prioritized and incorporated into the project plan?
How can we ensure that all changes are communicated effectively to all team members?
Building
What technical skills are needed to complete the build phase on time?
How can tasks be prioritized and assigned for efficient use of time?
What methods can be used to maintain clear communication among team members?
How will work integration and changes be managed to meet project requirements?

Quantum network for quantum cluster computing Project Timeline

Phase	Aug	Sept	Oct	Nov	Dec
Quantum communication network phase1	Build 2Qbit communication network				
Quantum router phase 1	Build quantum quantum router (2 nodes)				
Integration phase1		Integrate two rudimentary components	Testing and get feedback		
Improvement			Implement advanced features Enabling N - nodes		
Integration phase2				Integrate two components	Create dummy job for presentation
Documentation					Write technical documents for our clients to make them to use for their research
Research	Research and study quantum computation and cluster networking				

Risk and Risk Management / Mitigation

- Implementation Issues
  - Network and router design could just not work
    - Thoroughly checked with advisor and experts
- Creation of classical network
  - Issues concerning detection and design
    - Through research, keeping our advisor updated
- Merging of classical network and quantum network
  - Issues when combining and scheduling router swaps
    - We based our project on most fundamental quantum mechanics

Task Decomposition

- Steven & Benjamin - Creating new protocol for routing quantum information to the correct end node

- Ohik & Derrick - Building a simulation of each of the quantum nodes as well as the Quantum Router.

Personnel Effort Requirements

- Making sure healthy open lines of communication
  - Understanding each others thoughts and ideas

- 2 student lead meetings and an advisor lead meeting a week

Task	Person	Hours
Planning and design	All	30
Implementing 1 to 1 connection	Ohik & Derrik	70
Creating classical network packet	Steven & Ben	70
Implementing classical network in quantum network	Ohik & Steven	70
Troubleshooting	All	30
Documentation	Derrik & Ben	20
Presentation prep	All	20

Testing

Unit Testing

- Classical Network
  - Can the switch distribute tasks without error?
  - Can the nodes send error signals back to the router?
  - Can the router do the correct statistical analysis on the information?
  - Can the router schedule jobs optimally?

- Quantum Network
  - Can the router and node establish entanglement?
  - Can the switch and the nodes swap information accurately?
  - Can the switch and the nodes swap information quickly?

Interface and Integration Testing

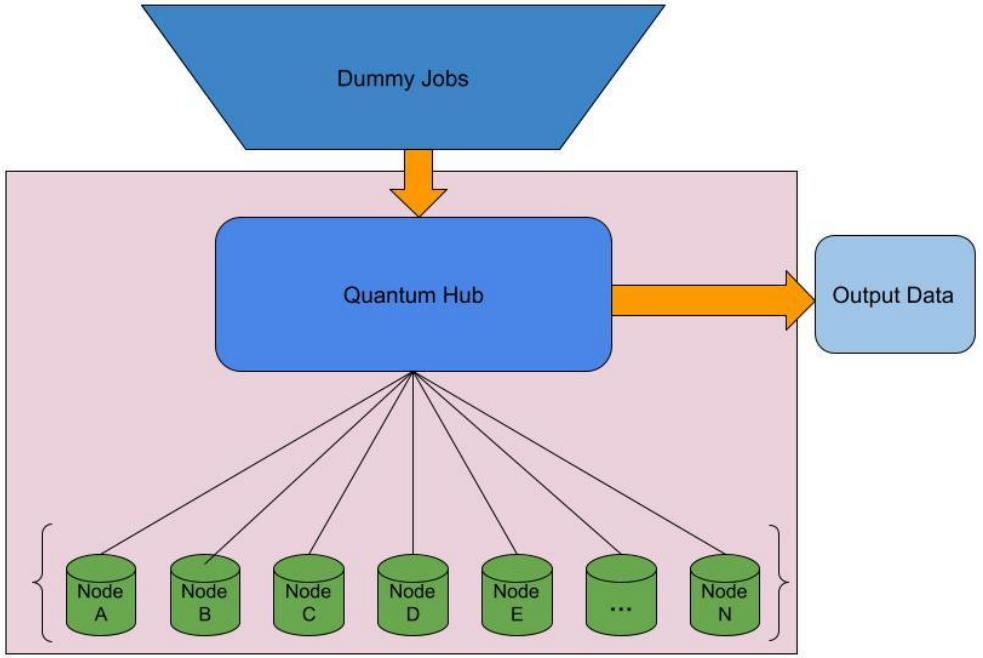
- Integration between the router and the nodes are critical for this project to work

- Interfacing these will require both the quantum and classical network to be working together

Acceptance and Regression Testing

Goals For testing:

- The router can communicate with nodes
- We can create as many nodes as our client needs
- The router can output desired data after analysis



Thank you

Supplement materials

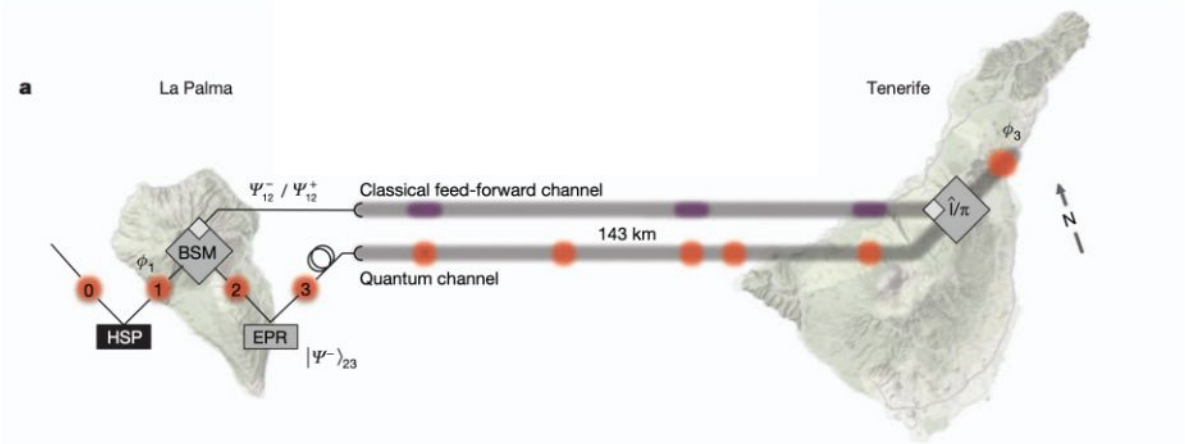
Superposition and Entanglement

Superposition

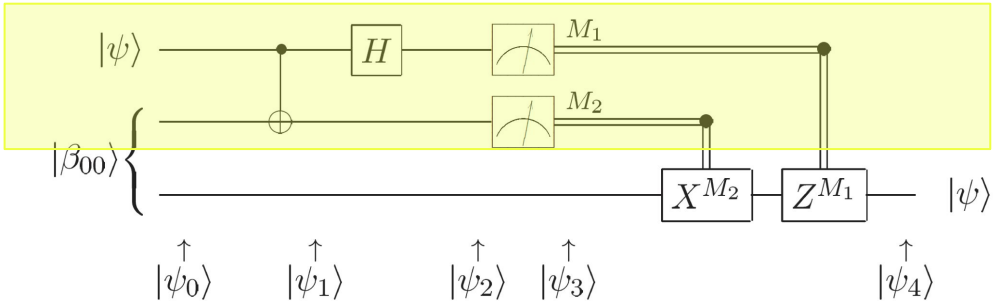
Denser information -> Solving complex problems

Entanglement

Quantum teleportation



1 Qbit teleportation by *Charles H. Bennett*



$$|\psi_0\rangle = |\psi\rangle|\beta_{00}\rangle$$

$$= \frac{1}{\sqrt{2}}\left[\alpha|0\rangle(|00\rangle + |11\rangle) + \beta|1\rangle(|00\rangle + |11\rangle)\right]$$

$$|\psi_1\rangle = \frac{1}{\sqrt{2}}\left[\alpha|0\rangle(|00\rangle + |11\rangle) + \beta|1\rangle(|10\rangle + |01\rangle)\right].$$

$$|\psi_2\rangle = \frac{1}{2}\Big[|00\rangle\,(\alpha|0\rangle + \beta|1\rangle) + |01\rangle\,(\alpha|1\rangle + \beta|0\rangle)$$
$$+ |10\rangle\,(\alpha|0\rangle - \beta|1\rangle) + |11\rangle\,(\alpha|1\rangle - \beta|0\rangle)\Big]$$

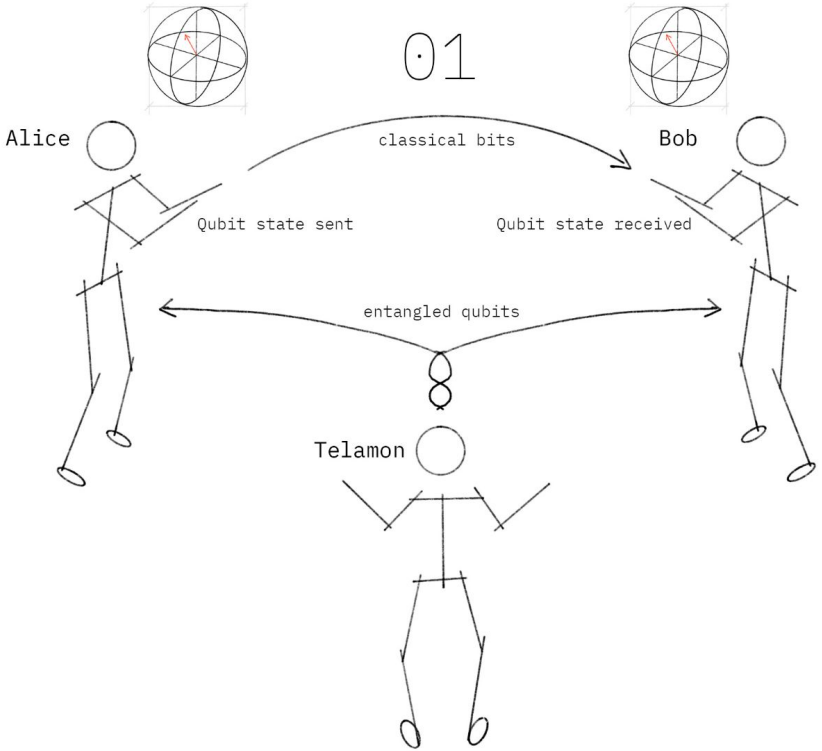
$$00 \longmapsto |\psi_3(00)\rangle \equiv \left[\alpha|0\rangle + \beta|1\rangle\right]$$

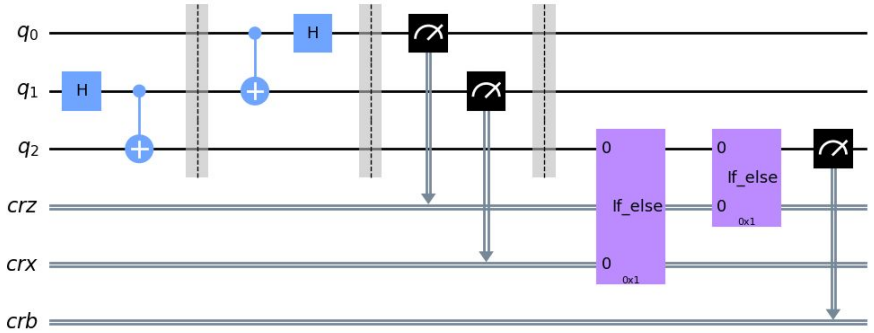
$$01 \longmapsto |\psi_3(01)\rangle \equiv \left[\alpha|1\rangle + \beta|0\rangle\right]$$

$$10 \longmapsto |\psi_3(10)\rangle \equiv \left[\alpha|0\rangle - \beta|1\rangle\right]$$

$$11 \longmapsto |\psi_3(11)\rangle \equiv \left[\alpha|1\rangle - \beta|0\rangle\right]$$

1 Qbit transportation simulation circuit





What we're doing is

1) Implement this in our network
2) Make it for more qbits
3) Implement security features
4) Implement error correction